Digital Controller Design and Implementation on a Buck-Boost Converter for Photovoltaic Systems

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Abstract

A photovoltaic (PV) systems are widely used to convert solar energy into electricity. The output of PV system is strongly affected by the weather. In order to maintain the stability of the electrical power, a rechargeable battery is necessary to temporarily store the electricity. The objective of this paper is to make the output voltage of solar panel constant in order to connect its 12V DC rechargeable battery in order to determine whether a change occurred in the input voltage or load. In our proposal, MATLAB-Simulink used to simulate the feedback controller for the power stage, referred to as the Buck-Boost converter. In addition, the Arduino Uno was applied as a PID (proportional, integral, derivative) controller, and the tested while connected to the converter. The results from MATLAB-Simulation and the Arduino Uno experiments will be compared and analyzed.

Keywords

Digital PID controller, Arduino Uno, Buck-Boost converter, Feedback controller, Photovoltaic system.

Introduction

The photovoltaic system is a part of the renewable energy that has a great significance in future energy systems. Low fuel costs and low maintenance are the benefits of solar energy systems, Petrone, et al.[1]. However, PV modules still have a relatively low efficiency conversion. The output voltage of these modules remain unstable due to weather changes, and thus making them nonlinear systems. Therefore, DC to DC converters have been used to control PV output voltage, Abouobaida and Cherkaoui [2]. DC to DC converters are used in Buck, Boost, and Buck-Boost at varied input voltage levels. The Buck-Boost converter, which is known as an inverting regulator, is shown in Figure 1. It is step up/ down converter that allows the output voltage to be greater or lower than the input voltage by change duty-ratio D.

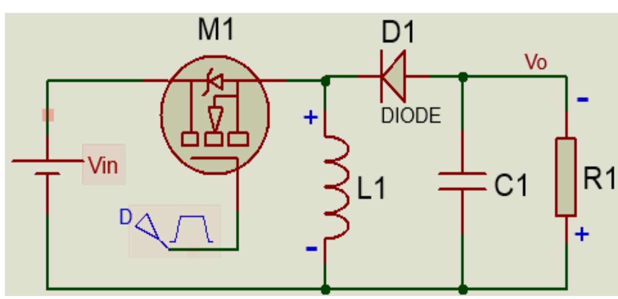


Figure 1: Buck – Boost converter

The output voltage depends on the duty cycle value, which goes from 0 to 1. Equation (1) shows the expression of the duty cycle of the Buck-Boost converter [3].

$$\frac{V_o}{V_i} = \frac{D}{1-D} \tag{1}$$

Where: V_o is the output voltage, V_i is the input voltage, and D is the duty cycle of power switches.

In order to get constant output voltage with minimum fluctuation, it is necessary to build a feedback circuit. There are many types of controllers that are used to diminish the oscillation of the converter output voltage such as P, PI, PD, PID, and fuzzy logic controller based on studies [4, 5]. The primary objective of those controllers is to control the duty cycle D in order to get the desired output voltage. In this paper, PID controller is utilized because it is possible to connect to a microcontroller such as Arduino Uno. The Arduino Uno can operate such a stand-alone device. PID controller has been used since the 1980s, to give a big jump to the process automation technology. Figure 2 shows the block diagram of PID controller with any system, where, all three K_p, K_i, and K_d gains are connected in parallel. The error signal is considered the input of the PID controller.

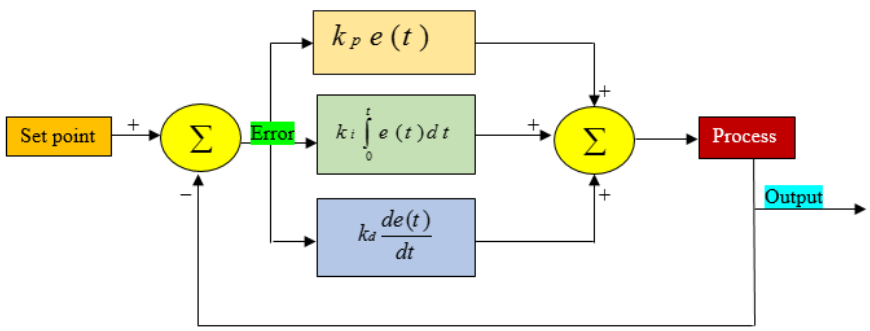


Figure 2: The block diagram of a PID Control

The PID control equation may be expressed in different ways, but an overall formulation is displayed in equation (2) [6].

$$u(t) = Kp\ e(t) + Ki \int e(t)dt + Kd\ \frac{de}{dt} \tag{2}$$

Where: K_p is proportional gain, is K_i integral gain, K_d is derivative gain, e is the difference between the output voltage value and the set point t: time or instantaneous time.

Modeling the Buck-Boost Converter with PID Controller

MATLAB-Simulink program is a graphical tool that can utilize to make a model of a block diagram for simulation and continuous test. By using Simulink program, the Buck-Boost converter with PID control is developed in Figure 3. Also, the Parameters of Buck-Boost converter are inserted in Table 1. Parameters have been chosen as the same as Power Pole Board values, which is educational kit for the implementation stage to get the accurate theoretical and practical results.

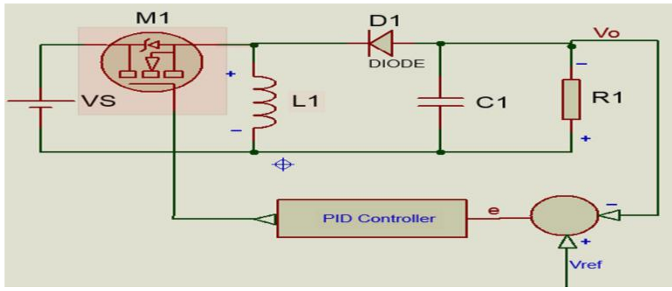


Figure 3: Buck-Boost converter with PID controller

components	Vin (v)	R load(Ω)	L (μH)	C (μF)	set point (v)
Values	9	20	100	697	12

Table 1: The Buck-Boost components

There are different possible techniques to find out the parameters of the PID controller. There are algorithm ways such as Genetic Algorithm and Bacterial Foraging Algorithm that can give accurate results. However, these two particular algorithms have the disadvantage of being slow to find out the PID parameters. Another method is PID manual tuning by using the Ziegler–Nichols tuning method that has an advantage of an online method and requires no math expressions. Another advantage of using the Ziegler–Nichols tuning method that it is an experimental way to tune a PID controller. This method was proposed by Jon Ziegler and Nichols in 1940s. In addition, it is achieved by setting I (integral) and D (derivative) gains to zero. The P (proportional) gain, K_p is then increased (from zero) until it reaches the final gain Ku, at which the output of the control loop fluctuates with a constant amplitude [7]. Table 2 shows the control gain obtained from Ziegler–Nichols tuning technique.

parameters	Kp (proportional gain)	Ki (integral gain)	Kd (derivative gain)
Values	22.56	116	0.0253

Table 2: PID controller gains

After running the MATLAB-Simulink, the step response output voltage of the Buck-Boost converter with PID control is shown in Figure 4 where the output voltage is constant 12V.

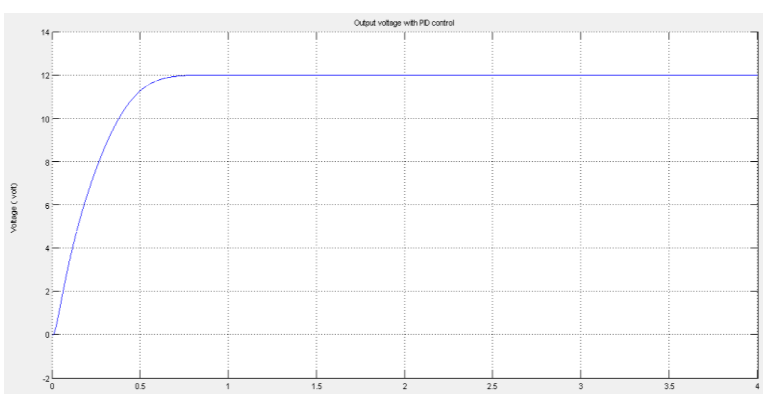


Figure 4: step response of output voltage of Buck-Boost converter

Moreover, the data of Check Step Response Characteristics block is used to catch on the characteristic of the output voltage that was recorded in Table 3 in order to find out rise time, overshoot, etc. Also, for more evidence, the output results are compared with results of the paper that is published by Rao, et al. [8].

parameters	Rise time (sec)	Percent Overshoot (percentage)	Settling time (Sec)	PercentSettling (percentage)
values	0.834	0.053	1.56	0.0019
paper- GA	0.0128	0.2092	0.0276	0.21
paper-BFOA	0.0129	0.2338	0.0204	0.74

Table 3: Comparison of results obtained from Ziegler–Nichols with GA and BFOA method

By looking at the step response characteristics table, the output voltage of the Buck-Boost converter taken 0.834 sec to reach the final value is 12 volt. The Table 3 shows overshooting of the signal is about 0.053% before settling time. However, the settling time start from 1.56 sec and the oscillation in the signal is 0.0019 % that is very small. The compassion clear demonstrations that the PID controller of GA and BFOA method is a faster response than our controller. However, our controller has less overshooting peak and more stability. That means there is no sudden jumping in current and slight swaying around the set point.

Implementation of the PID Controller

To implement the converter with PID control, the Power Pole Board and the Arduino Uno are used. The Power Pole Board is an experimental kit that is used to execute different experiments in power electronic lab. In this paper, Power Pole Board is used such a Buck-Boost converter. On the other hand, the Arduino Uno, which is the open source microcontroller, is utilized such as PID controller. Afterward, the code of PID algorithm in equation (2) got written by using Arduino C language. It is then downloaded into Arduino microcontroller ATmega328 to make it work as a stand-alone device [9]. The maximum analog input voltage at Arduino Uno is 6 volts. Therefore, a voltage divider that is already provided by the converter board is used to make Arduino operation in a safe side. Reduced output voltage of the converter is connected to analog Arduino Uno pin A0. To make this project more beneficial, the potentiometer is connected to analog pin A1 in order to obtain a wide range of reference voltages. However, its limitation depends on input-output voltage restrictions of the converter board. The advantage of the Arduino board is that it can give direct PWM outputs. We could avoid using another piece for PWM generation. Thus, this PID controller is less expensive microcontroller. The whole circuit has setup in Figure 5. Also, the potentiometer, which is an adjustable resistor, has been installed where a set point can be chosen. Furthermore, 9 volt lithium battery is connected to Arduino in order to take advantage of Arduino that is its operation such a stand-alone controller without using a PC-USB interface.

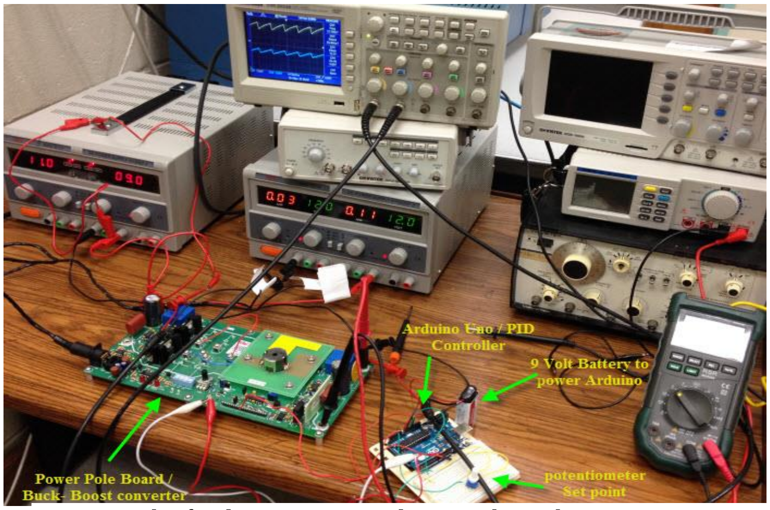


Figure 5: The final connection Arduino with Buck-Boost converter

Discussion and results

The frequency of Arduino itself is increased to reach 15 KHz. Figure 6 shows the increased frequency of PWM that generated from Arduino pin 9. Increasing the frequency of Arduino might not occur with download models from Simulink into Arduino microcontroller directly [9]. This is also a reason Arduino code is written instead of making direct interface with Simulink.

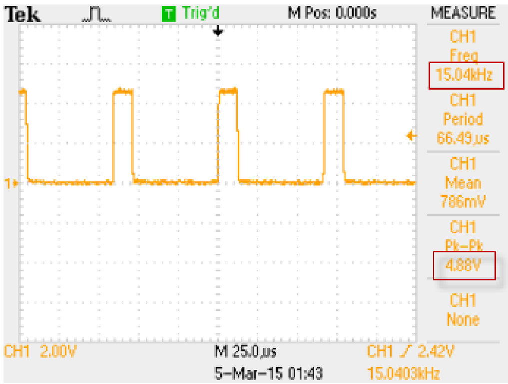
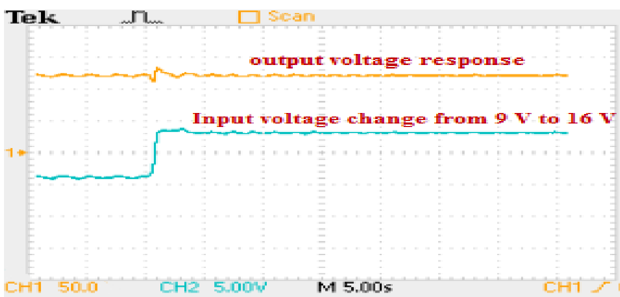
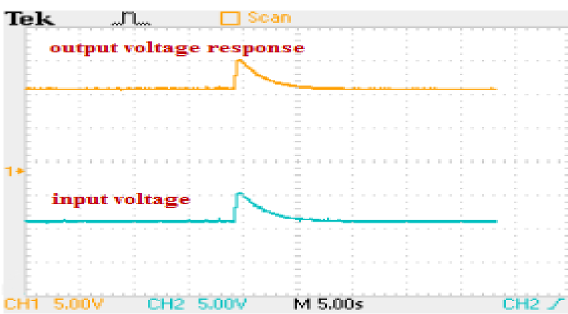


Figure 6: Arduino output PWM

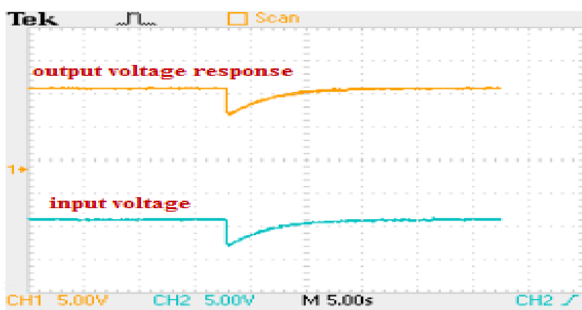
To prove the simulation results of hardware prototype for the Buck-Boost converter with the Arduino Uno, the results in the Figure **7** have been collected.



(a)



(b)



(c)

Figure 7: Results of closed loop output voltage

a: Output voltage response to input voltage changes from 9 to 16
b: Output voltage response to load changes from 40 to 70 Ω
c: Output voltage response to load changes from 70 to 40 Ω

Practically, digital PID controller has been tested in a lab. As shown in the Figure 7 (a) input voltage has changed from 9 to 16 volts, and it works correctly. However, there is still overshooting because the switching of voltage from 9 to 16 volts is performed manually from the knob of dc power supply, and the time of switching is about 3 sec. Furthermore, Table 4 from the paper of Javaid, et al.[10], shows the out voltage changes versus day of the time. The data collected on 23rd of July 2011 explained that a big change in voltage, blue highlighted, was 0.6 volt during 15 minutes. On other hands, our PID controller has been tested with voltage changes from 9 to 16 volts for about 3 second only. Consequently, the PID controller should work quite fine with photovoltaic systems.

Output Voltage	16.9	17.1	17.3	17.5	17.5	17.4	17.3	17.3	17.2	17.3	17	16.7	16.9	17.4	16.8
Time of Day	10:15 AM	10:30 AM	10:45 AM	11:00 AM	11:15 AM	11:30 AM	11:45 AM	12:00 PM	12:15 PM	12:30 PM	12:45 PM	1:00 PM	1:15 PM	1:30 PM	1:45 PM

Table 4: output voltage versus day of the time

Similarly, Figure 7 (b) and (c) shows the output voltage response to the varying in load where that load has been altered from 40 to 70 ohms and vice versa. The controller takes about 7 seconds to force the converter to come back again to steady state reference point which is 12V. Therefore, this PID controller works properly either charging a 12 volt battery or connecting straight to the load about 70Ω.

Conclusion

To apply the PWM control technique, Arduino is used to avoid the need for complex hardware circuits. The Arduino Uno can operate as a digital PID controller to regulate the output voltage of the Buck-Boost converter that could feed by a solar panel to get constant 12V or any desired voltage. The PID controller works properly whether input voltage fluctuates or there is a change in load. The non-oscillating output voltage can be used to charge 12V DC rechargeable battery or feed a load directly. The controller is simulated in MATLAB-Simulink, and the results are compared. Also, the hardware circuit is checked practically in a lab, and it operates correctly.

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